Using 3D Printing for thermoforming

Written by Ben Redwood

This article presents how 3D printing can be used to produce thermoform molds, recommends materials and discusses design recommendations.

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Introduction

3D printing continues to disrupt traditional methods of manufacture. Tooling is one area where the impact has been greatest. Just as 3D printing allows for the low cost, rapid manufacture of jigs and fixtures, the thermoforming industry has also embraced the versatility that 3D printing has to offer.

This article will discuss how 3D printing can be used to produce economic, functional thermoforming molds, offer advice on how to design 3D printed molds and present a range of materials that are best suited for the production of 3D printed thermoform molds. A case study will also present an example where 3D printing has been implemented successfully.

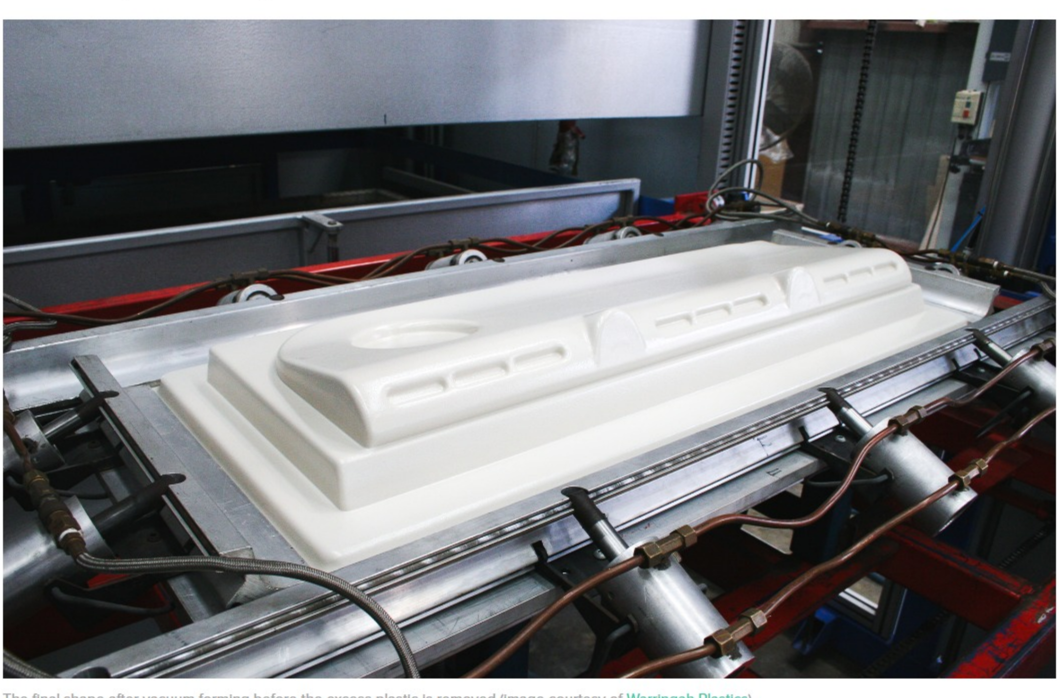
What is thermoforming?

Thermoforming is used to produce everything from plastic cups to hot tubs. The process involves heating a sheet of plastic up to a malleable state and then forcing it against a mold of a specific shape using different methods (generally vacuum or pressure forming). Once the plastic has cooled it is removed from the mold and excess plastic is trimmed to produce a final solid shape.

The process can be implemented at a low production level with single heated sheets of plastics being stretched over a mold, or at the high level where a continuous heated sheet is dropped over the mold, trimmed off and the process repeated.

Thermoforming is typically separated into 2 categories based on the thickness of the plastic sheet that is being molded; thin (less than 1.5mm) or heavy (thick) gauge thermoforming.

A heated sheet of plastic before forming



The final shape after vacuum forming before the excess plastic is removed (image courtesy of Warringah Plastics)

When to use thermoforming

Thermoforming is best compared to injection molding when considering it as an option for manufacturing parts. The advantages of using thermoforming include:

- Low cost tooling compared to injection molding.
- High repeatability.
- Suitable for a large range of thermoplastics.
- Large single piece part capability.
- Ideal for small to medium sized part runs of 50 – 3000 pieces.
- Creates aesthetically pleasing unpainted parts.
- Reduced lead times compared to injection molding.
- Very simple process to perform.

Some of the limitations of thermoforming include:

- Injection molding will produce parts to a higher level of accuracy.
- Parts are made from a single sheet of plastic eliminating designs with variable wall thickness.
- The process is unable to produce parts with undercuts or internal features.
- For production runs greater than 3000 parts, injection molding generally becomes more cost effective.
- Parts require excess plastic to be trimmed off.

Why use 3D printing?

Much like injection molding, thermoform tooling is produced via CNC machining. Tools are made of aluminium, are very expensive and difficult to iterate or modify.

3D printed molds have a number of advantages over traditional manufacturing techniques including:

Rapid design iterations making it ideal for prototyping

New mold designs typically require several iterations to perfect. The low cost nature of 3D printing methods coupled with the short lead times make it ideal for optimising a design.

Built in venting

Venting holes can easily be incorporated in a thermoform mold design resulting if no post machining being required.The porous nature of some 3D printing technologies means that often vent holes are not required at all.

High quality surface finish

Several 3D printing technologies are capable of producing parts with a surface finish equivalent to injection molding. This coupled with the ease of which parts can be sanded or post processed means that a high quality surface finish is achievable which directly relates to the quality of the formed part.

High quality surface finish

Molds often require complex contours and shapes that are difficult to produce with traditional manufacturing techniques. The additive nature of 3D printing means that it is able to easily produce complex geometries, undercuts and internal features.

An FDM thermoforming female mold (left) and the final molded part (right) (image courtesy of Stratasys)

3D printed materials

The technology and materials used for tooling for thermoforming must meet several requirements. These include:

- High level of detail.
- Smooth surface finish.
- Thermal stability.

Because of these requirements the 3 best methods of 3D printing for producing thermoforming molds are summarised in the table below and also compared to a mold made via CNC machining.

Technology	FDM	SLA	Material jetting	CNC
Material	Polycarbonate, Ultem, ABS, PPSF/PPSU	High temperature resins	Simulated ABS, VeroWhitePlus	Aluminium
Level of detail	Low	High	Very high	Very high
Surface finish	Poor, generally requires post processing	Very good	Excellent	Excellent
Porous	Yes	No	No	No
Lead times	Very short	Short	Short	Long
Cost	$	$$	$$$$	$$$$$
Sheet thickness	Thin and heavy	Thin	Thin	Thin and heavy
Best suited for	Low cost prototyping, simple geometries	Prototyping and production level	Prototyping and production level	Production level

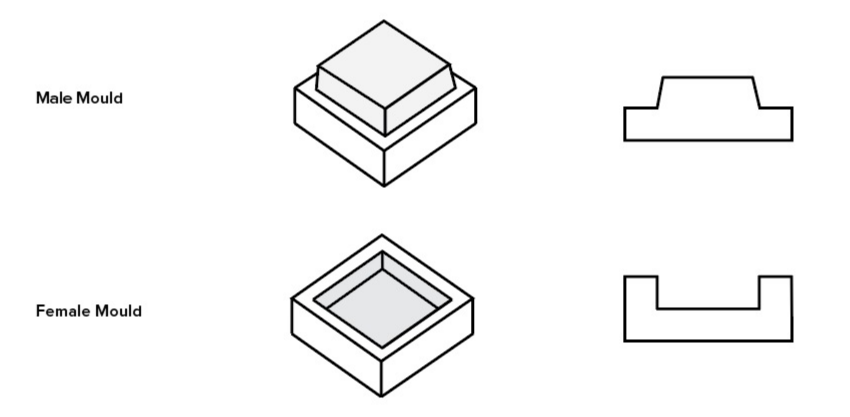
Note: Qualitative values are only in relation to the materials presented in this table.

Designing thermoform molds for 3D printing

For 3D printed molds the design should be orientated in the printer so that no support material is located on the molding face.

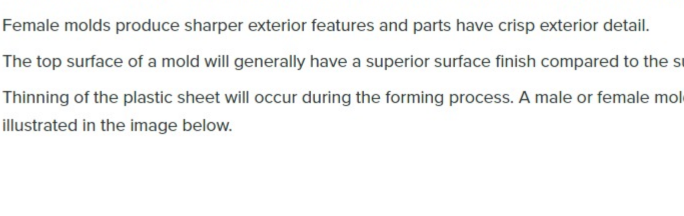
Male vs female mold

Moulds can be categorised into 2 groups; mate and female.



When deciding on the most appropriate mold for a specific application there are several factors to consider:

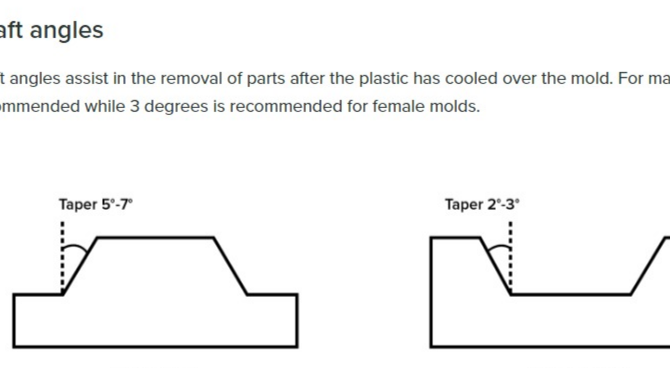
- Traditionally male molds were cheaper to manufacture making them more popular for prototyping before investing in more expensive female molds for high level manufacture. This is irrelevant when using 3D printing to produce molds.
- If it is required, male molds are generally easier to post process to a smooth finish. For mold printed via SLA or material jetting no post processing should be needed. For recommendations on how to post-process FDM printed parts refer to this article.
- Male tools are not able to produce sharp exterior detail and definition with parts having a more rounded appearance.
- Female molds produce sharper exterior features and parts have crisp exterior detail.
- The top surface of a mold will generally have a superior surface finish compared to the surface in direct contact with the mold.
- Thinning of the plastic sheet will occur during the forming process. A male or female mold will define where this thinning occurs as illustrated in the image below.



In general, female molds are the more desirable mold type.

Draft angles

Draft angles assist in the removal of parts after the plastic has cooled over the mold. For male molds a draft angle 5 degrees is recommended while 3 degrees is recommended for female molds.



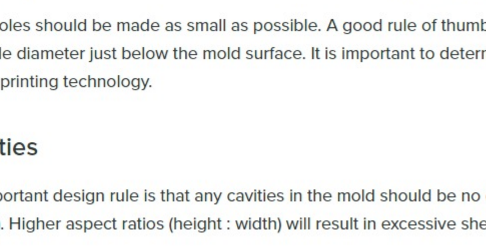
Venting

Vent holes allow for the evacuation of air trapped between the plastic sheet and the mold. Vent holes are best placed in the location where the plastic sheet makes last contact with the mold (typically edges, cavities and internal corners).

Vent holes should be made as small as possible. A good rule of thumb is half the final sheet thickness. A useful tip is to greatly increase the hole diameter just below the mold surface. It is important to determine the minimum hole diameter a printer is able to produce based on 3D printing technology.

Cavities

An important design rule is that any cavities in the mold should be no deeper that 75% of the width of the cavity opening (as shown below). Higher aspect ratios (height : width) will result in excessive sheet thinning and may cause sheet tearing.



Shrinkage

Most plastic sheets shrink during the vacuum forming process. Shrinkage rates depend on the type of plastic used and its thickness, but usually range between 0.4% and 0.8%. Shrinkage should be accommodated for in the mold design.

Mold release

Removal of a part from the mold depends entirely on the design of the mold. If generous tapers, no undercuts, good surface finish exist then removal should be fairly straight forward. Oil and silicone based sprays can be used to aid in removal as well as compressed up blown up through the vent holes.

Cooling

Production level 3D printed molds often require some cooling to limit thermal distortion due to repeated use. To limit these thermal effects many production molds incorporate channels for cooling fluid (typically water). These can easily be included in 3D printing designs but some post-print drilling may be required to achieve an accurate diameter.

Rules of thumb

- FDM is best suited for low run molds that do not include fine details and features.
- SLA and material jetting will produce molds with very smooth surfaces and fine details and are suitable for high level production.
- Female molds will generally produce parts of a higher quality with sharper features and a smoother exterior surface.
- Include draft angle of 3- 5 degrees, venting holes half the sheet thickness, no deeper that 75% of the width of the cavity opening and 0.4% and 0.8% shrinkage compensation in all 3D printed mold designs.

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